Conservation Probabilities of the Temperature Anomalies of Subsequent Months in the North-Atlantic-European Area

by

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Egymást követő hónapok hőmérsékleti anomáliáinak megmaradási valószínűsége az északatlanti-európai térségben. A tanulmány az északatlanti térség keleti felét és Európát magában foglaló, a 35 °W és 45 °E hosszúsági körökkel, s a 70 °N és 35 °N szélességi körökkel határolt szektor területéről kiválasztott 28 állomás 1901—1960 közötti havi középhőmérsékletei alapján vizsgálja az egymást követő hónapok hőmérsékleti anomáliáinak előjel szerinti megmaradási valószínűségét.

Megállapítja, hogy az anomáliák előjelének megmaradási valószínűsége az éven belül nem azonos, hanem erősebb—gyengébb évi menetet mutat. Ez az évi menet elsősorban Nyugat- és Közép-Európa térségében jellegzetes, ahol az anomáliák legnagyobb megmaradási hajlama nyáron, a legkisebb pedig ősz végén, tél elején mutatkozik. A reális statisztikai kapcsolatra utaló nagy megmaradási valószínűségekkel rendelkező hónappárok száma Közép-Európában jóval kevesebb, mint a vizsgált térség óceáni klimaterületein. Ezért ezen a területen a hőmérsékleti anomáliák hosszú távú előrejelzésénél felhasználható statisztikai módszerek alkalmazása korlátozott.

Die Erhaltungswahrscheinlichkeit der Temperaturanomalien der aufeinanderfolgenden Monaten in dem Nordatlantischen Raume. In der Arbeit wird auf Grund von 28 ausgewählten Stationen, welche sich in der östlichen Hälfte des Nordatlantischen Raumes und in Europa zwischen den Längenkreisen 35 °W und 45 °O und den Breitenkreisen 70 °N und 35 °N befinden, aus den Monatsmitteltemperaturen des Zeitraumes 1901—1960, die Erhaltungswahrscheinlichkeit des Vorzeichens der Temperaturanomalien von zwei aufeinanderfolgenden Monaten untersucht.

Es wird festgestellt, daß die Erhaltungswahrscheinlichkeit des Vorzeichens der Temperaturanomalien im Laufe des Jahres nicht die gleich ist, sondern einen schärfer oder schwächer ausgeprägten Jahresgang aufweist. Dieser Jahresgang ist in erster Reihe für West- und Mittel-Europa charakteristisch, wo die größte Erhaltungstendenz der Anomalien im Sommer und die geringste am Ende des Herbstes und am Anfang des Winters auftritt. Die Anzahl der Monatspaare, welche durch den hohen Wert der Erhaltungswahrscheinlichkeit auf die Existenz eines realen statistischen Zusammenhanges hinweisen, ist in Mittel-Europa bedeutend geringer als in den ozeanischen klimatischen Gebieten des untersuchten Raumes. Somit ist die Verwendungsmöglichkeit der statistischen Methoden für die langfristige Vorhersage der Temperaturanomalien in diesem Gebiete beschränkter.

In this study, we are investigating, on the basis of 28 selected stations situated in the eastern half of the North Atlantic and in Europe, between the longitudes 35 °W and 45 °E and the latitudes 70 °N and 35 °N, and the monthly temperature anomalies observed during the period 1901—1960, the conservation probabilities of the signs of temperature anomalies in subsequent months.

It is found, that the conservation probability values are not the same during a year, but they are exhibiting a more or less important annual variation. This annual variation is mainly in Western and Central Europe a characteristical one, where the highest tendency of the conservation of anomalies is appearing in summer, and the lowest is occurring at the end of autumn and at the beginning of winter. The number of high conservation probability values, indicating the existence of a realistic statistical relationship, is essentially lower in Central Europe than in the Oceanic area under investigation. Thus, the applicability of statistical methods in the field of long-range forecasting of temperature anomalies is rather a limited one in this area.

In the field of long-range forecasting of monthly anomalies of temperature, it is of a fundamental importance to elucidate the question, whether the time series of monthly anomalies can be considered as a chain of events that are independent from or, on the contrary, dependent on the antecedent values. Such investigations are also of further interest, in addition to their application in long-range forecasting, in studies on the general circulation of the atmosphere and from the point of view of a more fundamental knowledge of the statistical structure of meteorological time series. The latter application is yielding a possibility for a more precise formulation of the statistical models which are serving to the description of the time series of the anomalies.

In the present study, we are investigating, on the basis of monthly mean temperatures observed at 28 selected stations situated in Europe and in the eastern half of the Northern Atlantic area between the longitudes 35° W and 45 °E and between the latitudes 70 °N and 35 °N, during the period 1901 to 1960, the probabilities of the conservation of the signs of subsequent mensual temperature anomalies. The names and geographical co-ordinates of the stations used are listed in *Table I.*

Table I

Station network

Angmagssalik	65°37'N	37°34'W
Stykkisholm	65°05'N	22°44'W
Bergen	60°24'N	5°19'E
Bodo	67°16'N	14°22'E
Karasjok	69°28'N	25°31'E
Arkhangelsk	64°35'N	40°30'E
Valentia	51°54'N	10°15'W
Aberdeen	57°12'N	20°12'W
De Bilt	52°06'N	5°11'E
Berlin	52°27'N	13°18'E
Uppsala	59°52'N	17°38'E
Vilnius	54°42'N	25°18'E
Leningrad	59°58'N	30°18'E
Moscow	55°45'N	37°34'E
Okt. Gorodok	51°38'N	45°27'E
Paris	48°49'N	2°30'E
Marseille	43°27'N	5°13'E
Basel	47°33'N	7°35'E
Roma	41°48'N	12°36'E
Budapest	47°31'N	19°01'E
Sibin	45°48'N	24°09'E
Odessa	46°29'N	30°38'E
Ponta Delgada	37°45'N	25°40'W
Lisboa	38°43'N	9°09'W
Palma	39°35'N	2°41'E
Tunis	36°50'N	10°14'E
Athens	37°58'N	23°43'E
Nicosia	35°09'N	33°17'E

The basic material for these investigations was yielded by monthly mean temperatures of the stations contained in *Table I* observed during the period 1901—1960. In this way, the stochastic variables ξ_{ik} were available in the from of a matrix of the type $m \times n$, with

$$i = 1, 2, \dots 60$$

and

$$k = 1, 2, \dots 12$$

From the stochastic variables ξ_{ik} we derived the new stochastic variables ξ'_{ik} possessing only two values, namely $+1$ and -1. Designing by M_k the *median* of the distribution function of the stochastic variables situated in a given column of the matrix (that is, of the stochastic variables for a given month) we used in the course of the transformation the following values;

$$\begin{aligned} \xi'_{ik} &= 1 \qquad \text{when} \qquad \xi_{ik} \geqq M_k \\ \xi'_{ik} &= -1 \qquad \text{when} \qquad \xi_{ik} < M_k \end{aligned} \tag{1}$$

(corresponding to positive and negative anomalies, respectively).

It should be noted that this definition of the anomalies is at variance to that conventionally used in climatology, as the deviations are measured not from the arithmetic mean value. However, from the point of view of probability calculus, the use of the definition given under (1) is a more advantageous one, as in this way, the distorting effect of asymmetry is eliminated, and, as a consequence, both the positive and the negative anomalies are possessing one and the same probability of 0,5.

By forming the anomaly time series according to (1), we determined, for every consecutive pair of months k and $k+1$ the probabilities

$$P(+,+) \qquad \text{and} \qquad P(-,-)$$

that is, the probabilities for the occurrence of two subsequent positive and for the occurrence of two subsequent negative anomalies, respectively. Let us design the probability $P(+,+)$ by P_1 and the probability $P(-,-)$ by P_2. The probability of the conservation of the sign of anomalies is thus given by the sum P_1+P_2.

When assuming *independence* between the anomalies of subsequent months, and considering, that, according to (1),

$$P(+) = P(-) = 0{,}5$$

we have in this case

$$P_1 = P(+)\cdot P(+) = 0{,}25$$

$$P_2 = P(-)\cdot P(-) = 0{,}25$$

from which it is obtained, for the probability of sign conservation:

$$P_1+P_2 = 0{,}5$$

By selecting a confidence level of 95%, the assumption of independence should be, in the case of the data series under investigation, discarded when the empirically determined value of the sign conservation probability P_1+P_2 falls outside the following interval:

$$I = 0{,}5 \pm 1{,}96 \sqrt{\frac{0{,}25}{60}}$$

that is, when

$$P_1+P_2 > 0{,}627$$

or

$$P_1+P_2 > 0{,}373 \tag{2}$$

The conservation probabilities P_1+P_2 are contained in *Table II*. Let us consider the data collected in *Table* II. At first it may be stated that the conservation probability of the anomalies is not the same during the year, that is, a more or less

Table II

Conservation probabilities $P_1 + P_2$

	I—II	II—III	III—IV	IV—V	V—VI	VI—VII	VII—VIII	VIII IX	IX—X	X—XI	XI—XII	XII—I
Angmagssalik	0,63	0,60	0,53	0,60	0,57	0,55	0,67	0,65	0,55	0,55	0,43	0,58
Stykkisholm	0,48	0,63	0,50	0,58	0,63	0,67	0,67	0,55	0,65	0,43	0,55	0,56
Bergen	0,52	0,68	0,55	0,52	0,62	0,67	0,68	0,73	0,65	0,57	0,55	0,49
Bodo	0,48	0,68	0,62	0,53	0,55	0,65	0,63	0,57	0,63	0,58	0,62	0,58
Karasjok	0,50	0,55	0,62	0,55	0,58	0,53	0,57	0,53	0,60	0,50	0,60	0,68
Arkhangelsk	0,60	0,67	0,57	0,62	0,48	0,52	0,62	0,55	0,68	0,63	0,62	0,64
Valentia	0,63	0,63	0,78	0,67	0,52	0,63	0,58	0,63	0,58	0,53	0,63	0,62
Aberdeen	0,72	0,63	0,48	0,58	0,58	0,68	0,73	0,68	0,58	0,57	0,50	0,63
De Bilt	0,67	0,65	0,52	0,45	0,63	0,53	0,67	0,70	0,52	0,52	0,40	0,48
Berlin	0,58	0,63	0,60	0,60	0,60	0,48	0,62	0,60	0,72	0,47	0,50	0,54
Uppsala	0,67	0,67	0,57	0,65	0,65	0,60	0,70	0,62	0,62	0,58	0,53	0,54
Vilnius	0,62	0,60	0,65	0,60	0,63	0,55	0,58	0,65	0,68	0,57	0,47	0,63
Leningrad	0,60	0,65	0,63	0,62	0,57	0,50	0,72	0,57	0,67	0,62	0,53	0,63
Moscow	0,68	0,62	0,65	0,55	0,43	0,55	0,62	0,62	0,63	0,57	0,63	0,51
Okt. Gorodok	0,58	0,47	0,63	0,53	0,63	0,63	0,68	0,65	0,60	0,50	0,70	0,58
Paris	0,57	0,52	0,65	0,47	0,57	0,48	0,77	0,63	0,57	0,50	0,38	0,48
Marseille	0,60	0,62	0,52	0,58	0,63	0,60	0,65	0,70	0,57	0,43	0,48	0,58
Basel	0,63	0,53	0,63	0,47	0,58	0,55	0,77	0,55	0,60	0,53	0,40	0,58
Roma	0,63	0,65	0,52	0,55	0,65	0,67	0,70	0,58	0,53	0,65	0,48	0,54
Budapest	0,60	0,52	0,57	0'43	0,57	0,62	0,72	0,70	0,62	0,52	0,52	0,56
Sibin	0,67	0,52	0,53	0,50	0,53	0,57	0,63	0,68	0,52	0,60	0,53	0,61
Odessa	0,75	0,65	0,70	0,55	0,53	0,62	0,65	0,53	0,65	0,60	0,48	0,68
Ponta Delgada	0,58	0,50	0,47	0,65	0,65	0,62	0,70	0,68	0,65	0,48	0,48	0,66
Lisboa	0,57	0,55	0,67	0,65	0,53	0,53	0,55	0,58	0,58	0,63	0,50	0,54
Palma	0,68	0,60	0,63	0,57	0,45	0,63	0,55	0,63	0,53	0,77	0,65	0,53
Tunis	0,67	0,68	0,60	0,65	0,68	0,63	0,65	0,60	0,55	0,63	0,60	0,64
Athens	0,47	0,53	0,52	0,53	0,77	0,75	0,75	0,60	0,65	0,63	0,62	0,59
Nicosia	0,68	0,70	0,65	0,47	0,62	0,67	0,50	0,60	0,57	0,60	0,62	0,70

developed *annual variation* is experienced. The main characteristics of this annual variation are represented for the whole area under investigation, on *Fig. 1,* in which we have plotted the number of occurrence of the maximum and minimum values of the conservation probabilities on each of the 28 stations. The highest probability for the conservation of a temperature anomaly is occurring during midsummer from July to August, while the lowest one occurs in the transition period between autumn and winter, that is, from November to December.

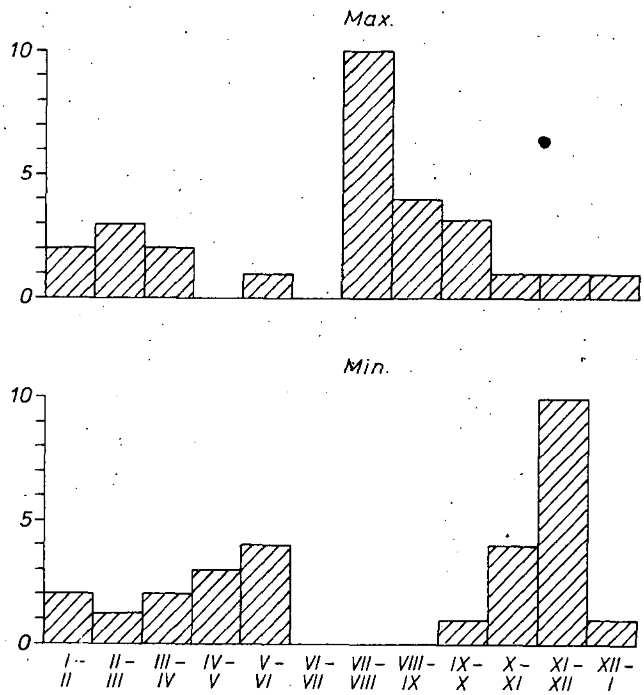

Fig. 1. Annual distribution of the maximum and minimum values of temperature anomalies
1. ábra. A hőmérsékleti anomáliák maximális és minimális értékű megmaradási valószínűségének éven belüli megoszlása

An essentially similar annual variation is exhibited by the frequency distribution presented on *Fig. 2,* which is yielding among the 28 stations the number of cases in which the value of the conservation probability was lying outside the limits of the independence interval according to (2), that is, it is yielding those months for which a statistical relation exists in respect to the signs of the anomalies. This annual variation is exhibiting, in agreement to the data presented on *Fig. 1,* a distinct accumulation of realistic relations in midsummer (July—August) and, in addition, on the end of the winter and the beginning of spring (February—March). Realistic relations are experienced rather seldom between the pairs of months November—December and April—May. Expressed in other words, this means that from the point of view of a prevision of the temperature anomaly of the subsequent month, July and February are yielding most information, while the least of information is obtained in April and November.

For obtaining a more detailed analysis of this interesting phenomenon, we are presenting the geographical distribution of the probability P_1+P_2 for the pairs of months July—August and February—March, respectively (*Fig. 3 and 4*). The higher conservation probability in midsummer is mainly characteristic for Western and Central Europe, where its value is exceeding 0,7 and on a smaller area, even 0,75. On the other hand, in the area of the Atlantic under investigation, and in Northern and Eastern Europe, lower probability values are encountered which are indi-

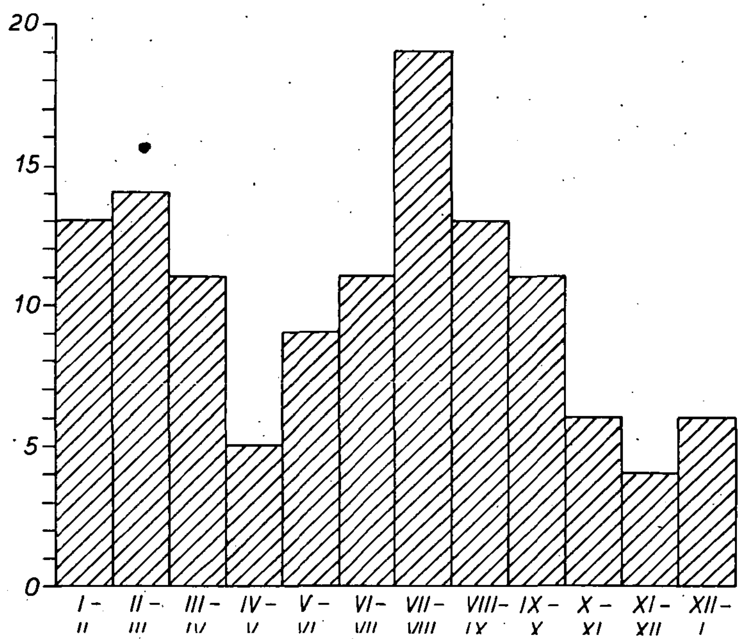

Fig. 2. Annual distribution of those values of conservation probabilities which are indicating the existence of a statistical relationship

2. ábra. Reális statisztikai kapcsolatot tükröző megmaradási valószínűségek éven belüli megoszlása

cating an independence of the subsequent anomalies. Thus it appears that the higher conservation probability of temperature anomalies in midsummer is primarily characteristic for the boundary regions between oceanic and continental climatic influences which is finally meaning that, in this area, a more prolonged persistence of both characteristics may occur. The exploration of the deeper causes of this phenomenon are affording further investigation. However the fact itself, as established here, should be taken intoconsideration during forecasting work. In the case of the second pair of months (February—March) an entirely different structure of the geographical distribution of conservation probabilities is exhibited. In this case, higher values of probability are appearing mainly in the North and, in our opinion, this is reflecting an effect of the disappearance of the winterly snow-cover. When, in the course of a winter, big snow masses are accumulated, then the melting of these snow masses is absorbing important quantities of energy, which is favourable for a prolonged subsistence of negative anomalies. At the same time, however, it is of interest, that even in the Mediterranean area, there is a higher probability for

VII. ⟶ VIII.

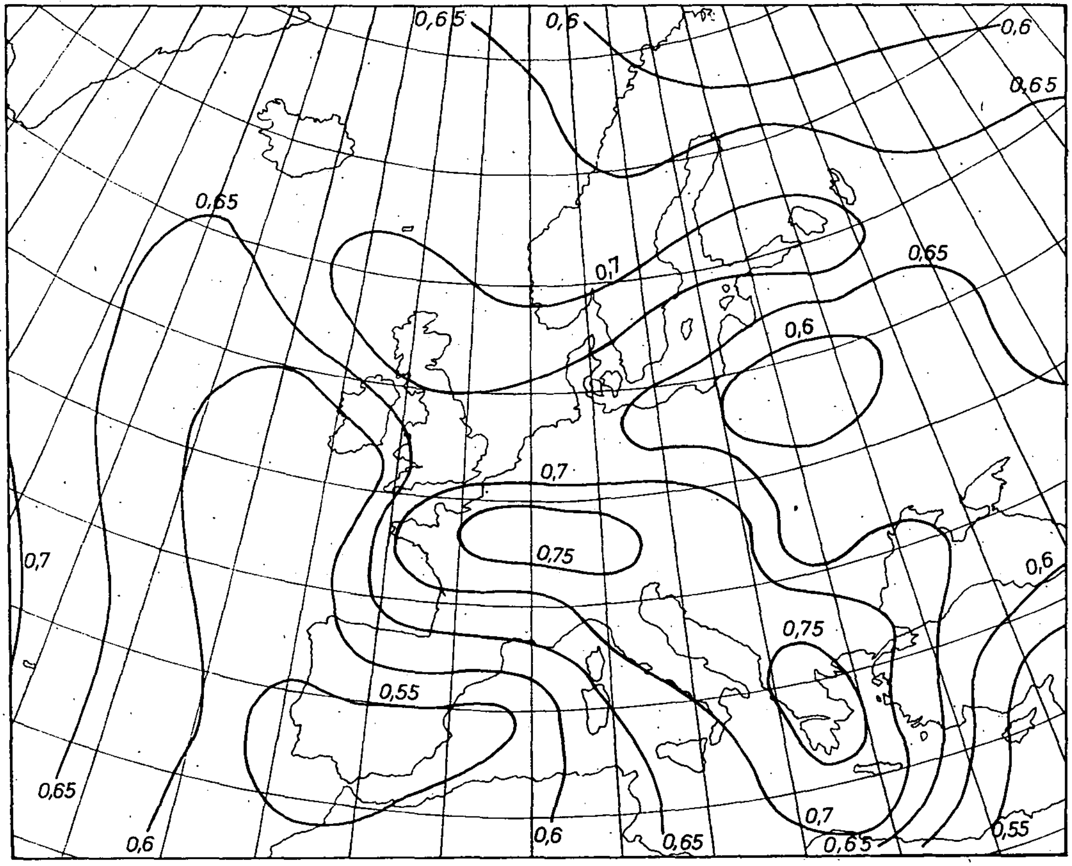

Fig. 3. Conservation probability of temperature anomalies for the pair of months July—August
3. ábra A hőmérsékleti anomáliák megmaradási valószínűsége júliusról augusztusra

the conservation of temperature anomalies, which is caused assumedly by the circumstance that the slower warming and cooling of water masses is equally favourable for the prolonged substistence of temperature anomalies having the same sing.

In the following we are dealing with the characteristics of the annual variation of conservation probabilities. As, already indicated, from *Table II* it appears that the conservation probability is possessing, on the majority of the stations under investigation, a characteristical annual variation. For solving the problem, whether this variation is in contradiction to the assumption of a uniform annual distribution of the probability (that is, whether the appearing annual variation is a realistic one), the following procedure may be used.

Let us determine the arithmetic mean value O_n of the conservation probabilities obtained for the 12 pairs of months. The maximum and minimum values of these probabilities will be designed by Q_{max} and Q_{min}. Let us consider the confidence interval of Q_m on the 95% level:

II.⟶III.

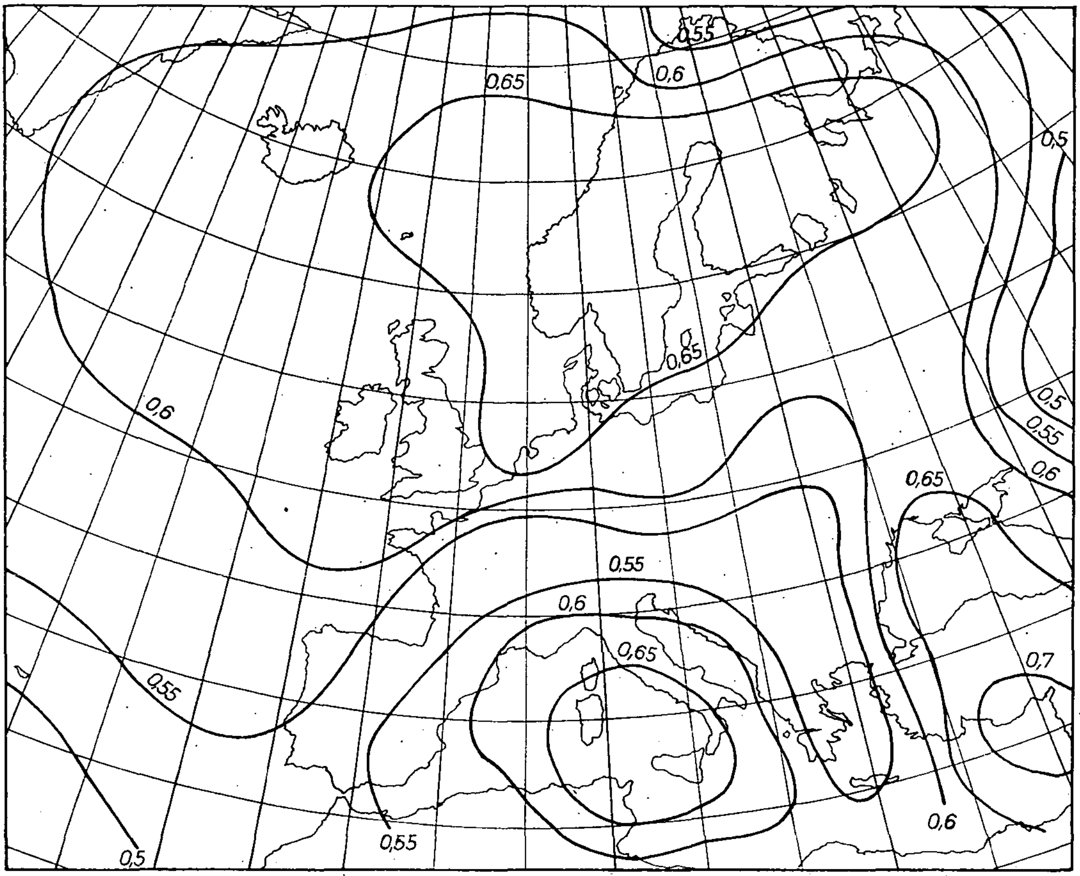

Fig. 4. Conservation probability of temperature anomalies for the pair of months February—March
4. ábra. A hőmérsékleti anomáliák megmaradási valószínűsége februárról márciusra

$$I = Q_m \pm 1{,}96 \sqrt{\frac{Q_m(1-Q_m)}{60}}$$

An annual variation is considered to be a realistic one, when the following conditions are fulfilled

$$Q_{\max} > Q_m + 1{,}95 \sqrt{\frac{Q_m(1-Q_m)}{60}}$$
$$Q_{\min} < Q_m - 1{,}95 \sqrt{\frac{Q_m(1-Q_m)}{60}} \tag{3}$$

A realistic annual variation of the conservation probabilities of temperature anomalies on the basis of the conditions (3) can be demonstrated for the following stations: De Bilt, Paris, Basel, Budapest, Odessa, Palma, Athens. We are separately

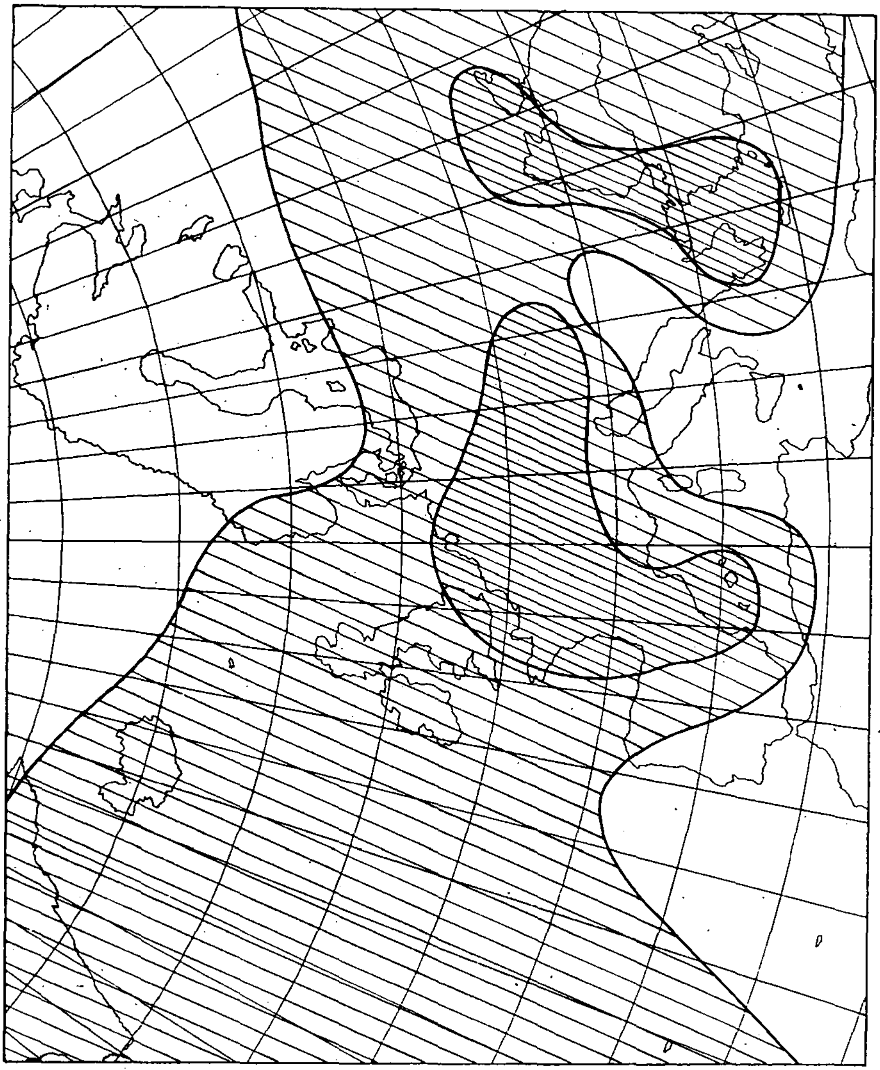

Fig. 5. Distribution of areas where there exists a realistic annual variation of the conservation probabilities of monthly temperature anomalies
5. ábra. Azon területek, eloszlása, ahol a havi hőmérsékleti anomáliák megmaradási valószínűségének reális évi menete fennáll

considering annual variations, for which only one of the conditions (3) is fulfilled. Such annual variations are found on the following stations: Angmagssalik, Stykkisholmur, Bergen, Valentia, Aberdeen, Berlin, Vilnius, Moscow, Okt. Gorodok, Marseille, Ponta Delgada, Nicosia. Separating the area represented by the above stations, we are obtaining a picture like that of *Fig. 5.* On this figure, we represented by a heavy shadowing the areas for which a realistic annual variation of the conservation probabilities is found on the basis of the conditions (3), while the areas are separated by a light shadowing where (3) is fulfilled only for Q_{max} or only for Q_{min}.

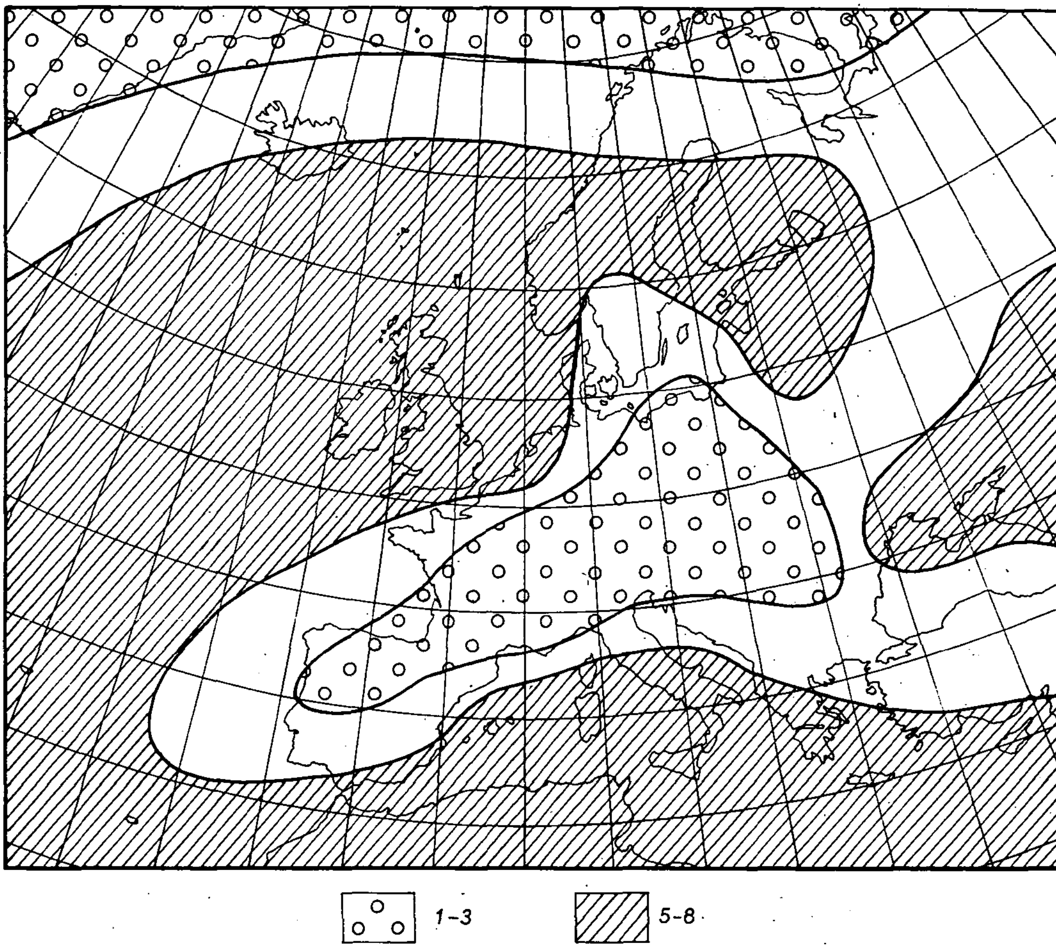

Fig. 6. Number of the pairs of months which are indicating the existence of a realistic statistical relationship between temperature anomalies
6. ábra. A hőmérsékleti anomáliák reális statisztikai kapcsolatára utaló hónappárok száma

The characteristic annual variation of conservation probabilities is primarily a feature of the middle-latitude regions of the European mainland, principally of Western and Central Europe and further it can be demonstrated in the south-eastern part of the Balkan peninsula and in the area of the Black Sea. These regions can be evaluated, from the point of view of the conservation of monthly temperature anomalies, as areas in which the anomaly of a previous month is yielding, in certain parts of the year, important information about the thermal character of the subsequent month (as seen before, this part of the year is, for Western and Central Europe, the midsummer).

In the following we are investigating the number of such pairs of months on the various stations, for which the conservation probability of the signs of temperature anomalies is indicating, on the basis of the criterion (2), the existence of a reâlistic statistical relation, that is, for which

$$P_1+P_2>0,627$$

The distribution of the numbers of such pairs of months is illustrated on *Fig. 6*. The number of the pairs of months indicating a statistical relation is lowest in Central Europe as well as in the area beyond the Arctic Circle (1 to 3), while in the central parts of the Atlantic, in the area of the British Isles, and in the Mediterranean basin, a much more higher frequency (5 to 8 pairs of months) is found. No doubt, this frequency distribution is indicating, that a higher persistence of temperature anomalies is mainly determined by the *distribution of oceanic and continental areas,* as a consequence of the well-known differences in the thermal balance of these two kinds of surfaces. However, it is very likely, that the characteristical band-like structure of the distribution of conservation probabilities which we have demonstrated is also connected to the characteristical types of the spatial distribution of montly temperature anomalies as discussed under [1], that is it may be also connected to circulatory causes.

Fig. 6. may be further evaluated from the point of view of long-range forecasting. As mentioned above, in the long-range forecasting of temperature anomalies, it is necessary to use, in addition to the dynamical-synoptical methods, also some statistical procedures. The figure is containing a warning, that the applicability of these methods may be, in the area of Central Europe, a much more limited one than in other areas of the world.

Reference

[1] *Péczely, G.:* A hőmérséklet havi anomáliáinak megmaradási hajlama az északatlanti-európai térségben (Tendency of persistence of monthly temperature anomalies in the area of the Northern Atlantic and of Europe). Időjárás, 80, 5. 267—273 pp.